EXPLORING THE PROTEROZOIC BIG SKY OROGENY IN SOUTHWEST MONTANA

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INTRODUCTION

The North American craton was built from roughly a half-dozen Archean blocks or provinces, largely stabilized between ≈ 3.0 and 2.5 Ga, which were subsequently welded together across Proterozoic collisional orogens between 2.0 and 1.7 Ga (Hoffman, 1988)(Fig. 1). In the western United States, this ancestral North American basement is revealed only in the cores of Mesozoic to Tertiary uplifted fault blocks, because younger deposits and younger events have buried and overprinted the Precambrian cratons. These fragmentary and discontinuous exposures provide the evidence by which the process of continental growth and the history of continental development can be reconstructed.

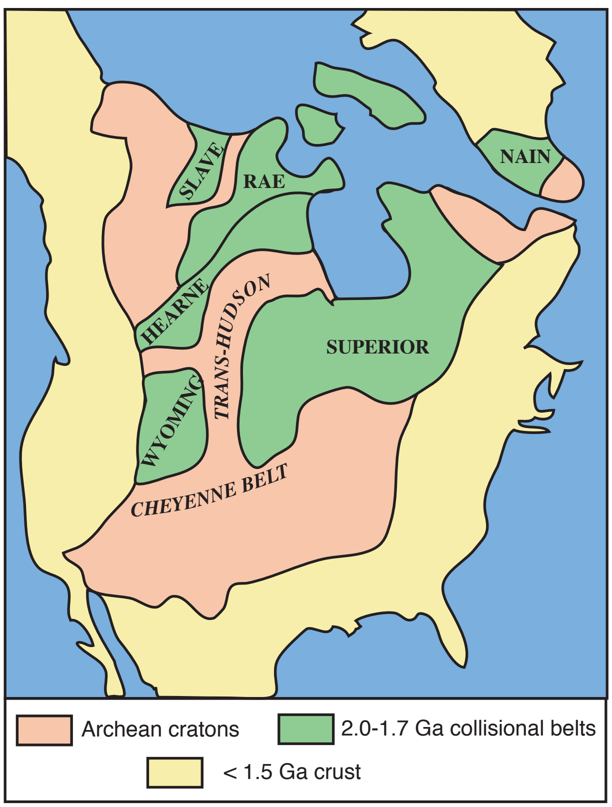


Figure 1: Archean cratons, including the Wyoming province, and Proterozoic collisional belts of the North American basement. Adapted from Hoffman (1988).

The Archean Wyoming province underlies much of Wyoming and southeastern Montana, extending into South Dakota, northern Utah and eastern Idaho (Fig. 2). It is flanked to the east by the Proterozoic Trans-Hudson orogen and to the south by the Proterozoic Cheyenne belt (Houston et al., 1993). The Rocky Mountain ranges of southern Montana - including the Tobacco Root, Highland, Madison, Ruby, Greenhorn, Gravelly, and Beartooth Mountains (Fig.2) – lie at the northern limit of exposure of the Wyoming province. The Medicine Hat block, part of the Archean Hearne province, underlies southern Alberta to the north. Any suture zone that may exist between the Medicine Hat block and the Wyoming Province is not exposed. A linear array of long-lived faults, Mesozoic to Tertiary intrusive rocks, and geophysical anomalies known as the Great Falls tectonic zone, however, has been identified across northern Montana between the two Archean provinces and is thought to represent a profound lithospheric boundary (O’Neill and Lopez, 1985).

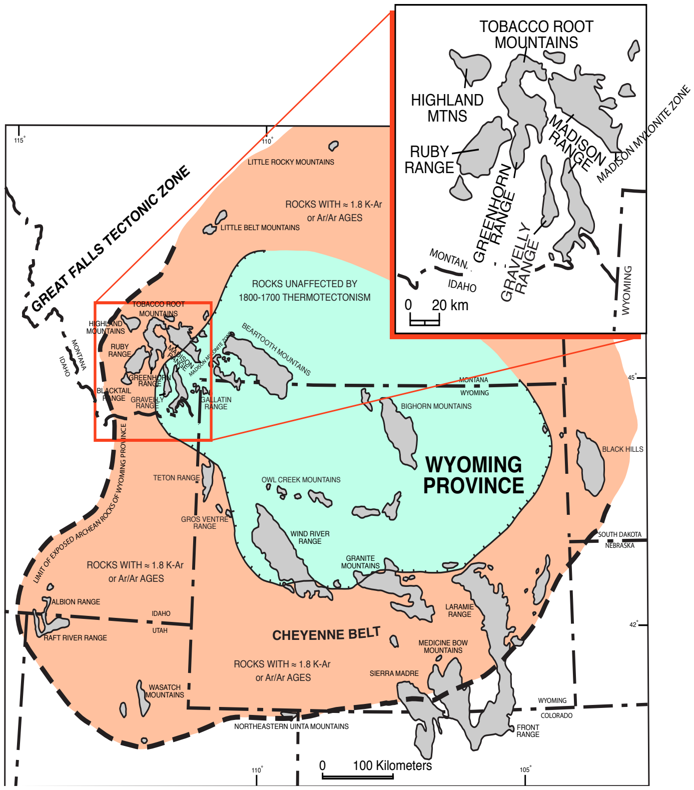
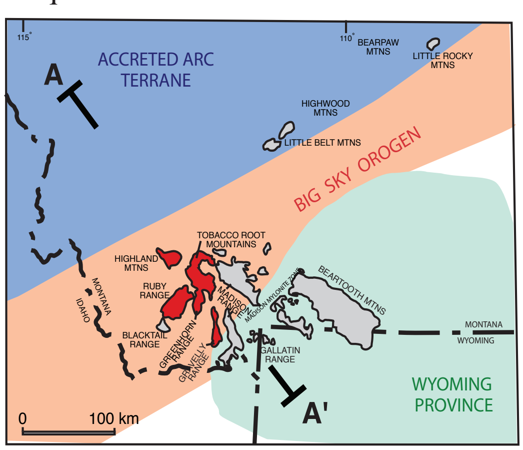


Figure 2: Wyoming province and flanking Proterozoic collision belts. Grey areas are exposures of basement rocks in Laramide ranges. Inset map shows the ranges of the study area.

The geology of the northern Wyoming province is dominated by quartzofeldspathic gneisses with interlayered amphibolites, which are juxtaposed with heterogeneous suites of metasupracrustal lithologies such as pelitic schists, quartzites, iron formation, and marble in varying proportions (Mogk and Henry, 1988). Gneisses of the northern Wyoming province are derived from some of the oldest rocks preserved in North America, ranging to 3.5 Ga (Mueller et al., 1996), and it had been assumed that the dominant character of the northern Wyoming province was acquired in the Archean.

Keck projects in 1993, 1995, and 1997 studied the geology of the Precambrian core of the Tobacco Root Mountains. Among other results, this work revealed a previously unappreciated Proterozoic history of high-grade metamorphism, complete recrystallization, and penetrative deformation that largely obliterated any older Archean origin the rocks may have had (Brady et al., 2004a). The intensity of the Proterozoic thermotectonism in the Tobacco Root Mountains is comparable to the character of the deep roots or crystalline cores of collisional orogens. On this basis, we call the event that metamorphosed the Tobacco Root Mountains the "Big Sky orogeny", and hypothesize that it was regional in extent, probably affecting basement rocks all along the northern flank of the Wyoming province. Regional geologic relationships suggest the Big Sky orogeny may have occurred during the collision of an arc terrane and the amalgamation of the Medicine Hat block to the Wyoming province (Harms et al., 2004) (Fig. 3). In the Tobacco Root Mountains, the Big Sky orogeny is well dated between 1.78 and 1.72 Ga (Cheney et al., 2004a; Mueller et al., 2004, Brady et al., 2004b)



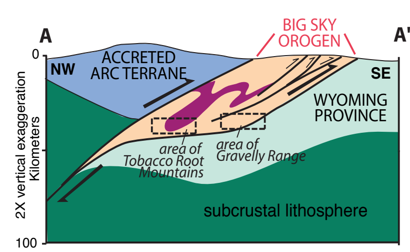


Figure 3: Schematic map and cross section of the Big Sky orogen. Adapted from Harms et al. (2004).

PROJECT GOALS

The goals of the 2005-06 Montana project were to examine evidence for the Big Sky orogeny in the Precambrian cores of Rocky Mountain ranges surrounding the Tobacco Root Mountains and to develop a greater understanding of the large-scale architecture of the orogen.

Metamorphic rocks in the Tobacco Root Mountains preserve a detailed history of the evolution of the Big Sky orogen (Cheney et al., 2004b) (Fig. 4), which includes:

- an initial clockwise pressure-temperature loop from peak pressures of metamorphism at > 1.0 GPa to peak temperatures at > 700˚C, which is typical of tectonic burial beneath accumulating layers of a collisional orogen;
- subsequent isobaric cooling, attributed to continued convergence, which thrust the Tobacco Root Mountains rocks over cooler, shallower rocks; and
- isothermal decompression, which may be the result of extensional unroofing of this part of the core of the Big Sky orogen.

A working hypothesis for the project was that these different types of tectonic juxtapositions might be found surrounding the Tobacco Root Mountains, along strike, or at structurally higher or deeper levels of the orogen.

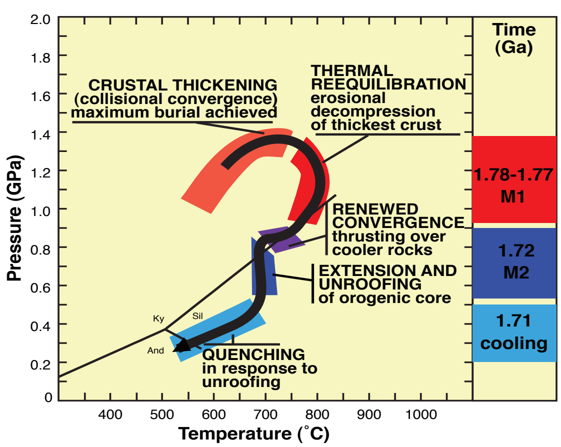


Figure 4: Pressure-temperature-time path for metamorphism associated with the Big Sky orogeny in the Tobacco Root Mountains. Adapted from Cheney et al. (2004b).

The project sought to:

- establish areas affected by the Big Sky orogeny;
- assess the distribution of the high grade crystalline core and lower grade external zones of the foreland of the orogen;
- compare and contrast the geologic histories of these domains, including the pressure and temperature of metamorphism and deformation, and the timing of the orogenic event; and
- identify and analyze key contacts between different domains or different sequences of rocks within the orogen, determining the direction of displacement (if any) across the contact.

RESEARCH
Highland Mountains

The Highland Mountains lie along structural strike of the Big Sky orogen to the west of the Tobacco Root Mountains. O'Neill (1995) interpreted the Precambrian basement of the Highland Mountains as a NE-SW elongate structural dome, with quartzofeldspathic gneisses dominant in the core, and biotite gneisses dominant in the surrounding, higher level "cover" of the dome. The core of the dome lies along the eastern flank of the Highland Mountains, closest to the Tobacco Root Mountains but separated from them by the valley of the Jefferson River.

We found that the geologic character of the core of the Highland Mountains dome is very similar to that of the Tobacco Root Mountains, including the dominance of quartzofeldspathic gneiss with interlayered amphibolite, the presence of distinctive cross-cutting metamorphosed mafic dikes and sills within those gneisses, and the occurrence of a thin heterolithic marker sequence of metasupracrustal rocks that includes a megacrystic gedrite-garnet gneiss. On the other hand, cover gneisses that flank the core of the

Highland dome are quite different from rocks in the Tobacco Root Mountains, in particular a widespread biotite-garnet-sillimanite schist, and a suite of leucocratic mylonitized sills and dikes, localized along the core-cover contact, which have yielded a $^{40}Ar/^{39}Ar$ age of intrusion of ≈1.79 Ga (O'Neill, 1995).

These comparisons and contrasts with the adjacent Tobacco Root Mountains are being investigated in greater detail.

Jess Matthews studied pressures and temperatures of metamorphism in the gedrite-garnet gneiss and co-occurring metasupracrustal rocks in the eastern core of the Highland Mountains dome. These can be compared to conditions of metamorphism enjoyed by very similar rock types in the Tobacco Root Mountains.

Stephanie Moore has analyzed the major and trace element geochemical character of the metamorphosed mafic dikes and sills for comparison with similar bodies in the Tobacco Root Mountains and to constrain the origin of both.

Tyler Hannah investigated the kinematics of the mylonitic rocks, especially the leucocratic sills, along the contact between the Tobacco Root Mountains-like gneisses of the core of the dome and the distinctive Highland Mountains rock types in the cover.

Julia Labadie has studied the metamorphism and shear in biotite-garnet-sillimanite gneisses from select locations in the cover rocks of the dome, concentrating on the well-exposed rocks along Camp Creek in the northern Highland Mountains, farthest from the dome's core.

Gravelly Range

Compositional layering and metamorphic fabric regionally dip to the NNW, so deeper structural levels are reached in the Gravelly Range relative to the Tobacco Root Mountains, and from north to south within the elongate Gravelly Range. The northern end of the Gravelly Range and the adjacent Greenhorn Mountains appear to be an extension of the Tobacco Root Mountain domain. Both are underlain by quartzofeldspathic gneiss and interlayered amphibolite. The geology of the rest of the Gravelly Range, however, contrasts sharply with that of the Tobacco Root and Highland Mountains. In the northern Gravelly Range, quartzofeldspathic gneiss gives way to a suite of high grade, sillimanite and kyanite-bearing metasupracrustal rocks. Immediately to the south, across the central Gravelly Range, a heterolithic sequence of interlayered metasedimentary and mafic meta-igneous rocks is at such low grade of recrystallization that relict sedimentary structures and pillows are preserved. In the southern Gravelly Range, mafic bodies are large enough to have produced sizable contact metamorphic aureoles in the low-grade host rocks. The metasedimentary suite of the central and southern Gravelly Range is flanked to the east and southeast by a number of distinctive granitic gneisses and gray quartzofeldspathic gneisses. The southernmost of these gneisses have been correlated with the Archean basement of the Madison and Beartooth Ranges (O'Neill and Christiansen, 2004), and may be more typical of the stable Wyoming province than the Big Sky orogen.

The structural and lithologic character of the low grade metasedimentary and mafic meta-igneous suite of the central Gravelly Range has been investigated by ***Libby Klein***, in order to constrain the protoliths of these rocks, the environment in which they originated, and to characterize the history of tectonism they experienced.

Alyssa Doody has analyzed the distinctive contact metamorphic aureole associated with mafic intrusive bodies in iron formation. Mineral chemistry across the aureole delineate the pressure and temperature conditions at the time of intrusion.

Arthur Schwab conducted a geochemical and kinematic analysis of mylonitic granitic gneiss on the eastern flank of the central Gravelly Mountains to help characterize the kind of displacements responsible for juxtaposing contrasting rock suites in the Gravelly Range and for comparison with other quartzofeldspathic gneisses of the Gravelly Range.

Braden Fitz-Gerald has undertaken a major and trace element analysis of the ?Archean gray gneisses in the southernmost Gravelly Range and has prepared samples of these rocks for U-Pb zircon geochronology. His work explores the relationship of these gneisses to those in the core of the Big Sky orogen.

Regional Relationships

We have found that there are differences between the suites of rock and grade of metamorphism in the Tobacco Root Mountains, the Ruby and Greenhorn Mountains, the central and southern Gravelly Range, and in the core and cover of the Highland Mountains dome. Nevertheless, have we also observed commonalities. These commonalities provide an opportunity to survey trends across the study area of the Big Sky orogen. Quartzofeldspathic gneiss and amphibolite occur in the Precambrian basement of each of the southwestern Montana Rocky Mountain ranges. In some, quartzofeldspathic gneiss and amphibolite are volumetrically dominant and are intimately interlayered, suggesting a common origin and a setting that was paleogeographically significant in the history of the northern Wyoming province. In others, quartzofeldspathic gneiss is a minor constituent and amphibolite occurs as isolated lenses or pods within metasupracrustal rocks.

Emily Fertig has conducted major and trace element geochemical analyses of representative quartzofeldspathic gneisses collected from all of the study areas of the Big Sky orogen.

Similarly, ***Eric Siegel*** has analyzed the geochemistry of amphibolites throughout the study area. Both Emily and Eric will better constrain the setting or settings in which these rocks originated, the possible protolith character of the metamorphic rocks, any genetic relationship between the felsic and mafic rock types, and whether or not there are differences between gneisses in different study areas.

Metasupracrustal suites in the Tobacco Root, Highland, northern Gravelly, and southern Gravelly Mountains differ in the proportion and range of rock types they include. It is not clear whether these suites are a single depositional and extrusive unit that once stretched across this part of the Wyoming province, or if they represent different deposits that did not correlate in space or time. To one degree or another, however, all of the metasupracrustal sequences include pelitic schists.

This affords ***Deanna Gerwin*** the opportunity to compare metamorphic grade across the study area by examining one consistent rock type. Deanna has analyzed mineral chemistry for thermobarometric determination of pelitic schists from all areas of the Big Sky orogen study area.

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